with an average of 97.3% (see Figure 1 for an example of pass-rate vs. gantry angle result). Using this method, a problem with the gantry motor control with one linac at our centre was found, which was corroborated (albeit at a much higher time cost) by commercial VMAT QA products, further proving its utility in a clinical setting.

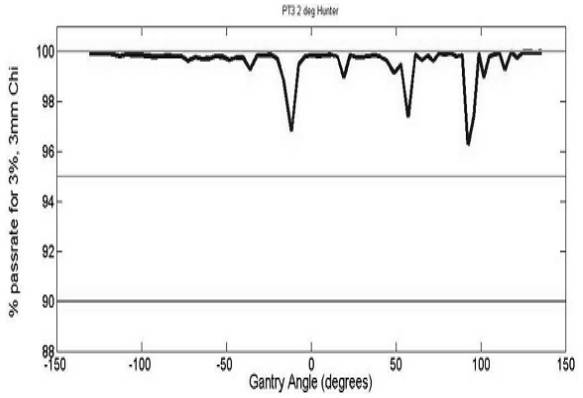

Figure 1. Chi results comparing EPID images to predicted images for each sub-arc during a complete VMAT delivery.

Conclusions: The method provides a comprehensive and highly efficient pre-treatment verification of VMAT delivery using EPID. Dose delivery accuracy is assessed as a function of gantry angle to ensure accurate treatment. Individual Chi maps for small sub-arcs provide a useful tool for error diagnostics.

OC-0157

Sensitivity of EPID-based in vivo dosimetry to detect errors during VMAT delivery

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Purpose/Objective: In volumetric-modulated arc therapy (VMAT) gantry speed, multileaf collimator configuration, and dose rate vary continuously during delivery. For a safe clinical implementation of VMAT, accurate 3D dose verification is essential but also complicated. In our department, EPID-based *in vivo* dosimetry using a semi-empirical back-projection model is clinically employed to verify all VMAT treatments. The purpose of this study was to investigate the sensitivity of our 3D *in vivo* EPID dosimetry approach to detecting patient-related errors during VMAT delivery.
Materials and Methods: Treatment planning of VMAT was performed using the SmartArc module of the Pinnacle treatment planning system. In order to assess the sensitivity of our EPID-based *in vivo* dosimetry method, patient-related errors were simulated by changing position and dimension of an anthropomorphic (Alderson) phantom. The phantom was irradiated using a 2-arc head-and-neck (6 MV), prostate (10 MV) and lung (10MV) VMAT technique. The errors comprised a vertical and horizontal phantom shift of 2 cm, a 10 degree rotation, and the addition of 1cm tissue-equivalent material. Dose distributions reconstructed from EPID images and the original planned dose distributions were compared using 3D γ evaluation using 3% dose difference relative to the maximum dose, and 3 mm distance-to-agreement as criteria.
Results: Table 1 shows the 3D gamma evaluation of the total dose relative to the situation without errors. For the prostate treatment, the effect of the introduced errors is negligible, except that the reconstructed dose at the prescription point was 4.2% higher for a change in thickness of 1 cm. For the head-and-neck treatment, results for the gamma evaluation showed a larger sensitivity for the introduced errors. Also the dose difference at isocenter for the thickness error was larger: -7.8%. The results for the lung plan were similar to those for the prostate plan.

Table 1. Gamma Evaluation Results (3%, ±3mm) and Relative Dose Differences at Isocenter for Introduced Errors

Treatment Site	Error Type	γ_{mean}	$\gamma_{1\%}$	$\gamma_{\leq 1}$(%)	Relative Dose Difference at Isocenter(%)
Prostate	Vertical shift	0.41	1.2	96.7	0.8
	Horizontal shift	0.30	0.8	99.9	0.4
	Rotation	0.30	0.9	99.5	0.6
	Thickness	0.66	1.4	86.9	-4.2
Head-and-Neck	Vertical shift	0.90	3.8	69.6	1.1
	Horizontal shift	2.23	8.3	36.1	5.1
	Rotation	0.77	3.9	77.5	-1.2
	Thickness	0.81	2.5	72.1	-7.8
Lung	Vertical shift	0.42	1.2	97.4	-0.7
	Horizontal shift	0.35	1.0	98.9	-1.2
	Rotation	0.49	1.8	92.7	0.1
	Thickness	0.59	1.5	91.9	-7.0

Conclusions: Our verification results show that vertical and horizontal shifts and a rotation of the order of 2cm and 10 degree, respectively, do not result in significant deviations between EPID reconstructed and treatment plan dose distributions for both prostate and lung VMAT treatments. The head-and-neck VMAT treatments are more sensitive for position errors. With VMAT, EPID dosimetry is often not able to detect patient position discrepancies, and should be combined with IGRT. However, changes in patient thickness are easily detected.

OC-0158

Correlation of 3D gamma evaluation with DVH and EUD parameters from in vivo portal dosimetry of head-and-neck VMAT

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Purpose/Objective: For *in vivo* verification of IMRT and VMAT treatments a 3D dose reconstruction method based on EPID dosimetry is routinely applied in our clinic. After reconstruction, the *in vivo* dose is compared to the planned dose by means of a 3D γ analysis. Although this method is capable of detecting treatment deviations, the clinical relevance of γ parameters is far from obvious. Therefore, we wish to correlate the 3D γ evaluation results with other, clinically more common parameters used to determine the quality of a dose distribution, such as DVH and EUD parameters for specific regions of interest (ROIs). As a pilot study, head-and-neck (H&N) VMAT treatments were investigated.
Materials and Methods: 18 treatments were selected having a variety of deviations in the *in vivo* dose, combined with a few treatments showing no deviations. For 56 fractions of these treatments, the 3D *in vivo* dose distribution was reconstructed. Several parameters were calculated for three different ROIs: the PTV, the volume enclosed by the 50% isodose surface and the volume enclosed by the 30% isodose surface minus the PTV. These ROIs were chosen to be representative for our current clinical portal dosimetry evaluation, and to clearly separate high- and low-dose regions. The calculated γ parameters were the γ pass rate, 99th percentile of the γ-distribution (γ1%) and the mean γ value. Differences between planned and reconstructed dose distributions were next evaluated for each ROI using DVH parameters D1, D50 and D99 and EUD(1), i.e., the mean dose and EUD(7), i.e., focusing on hot spots. Since γ values carry no sign, correlations between absolute deviations of DVH and EUD parameters and γ parameters were evaluated.
Results: The table shows the obtained correlation coefficients. For all ROIs, strong correlations are observed between γ1%, mean γ and DVH and EUD parameters. The D99 parameters, however, hardly correlated with anything, except weakly with parameters of the 50% and 30%-PTV ROIs.

ROI	γ parameter	|D1^{EPID} - D1^{plan}| (%pt)	|D50^{EPID} - D50^{plan}| (%pt)	|D99^{EPID} - D99^{plan}| (%pt)	|EUD(1)^{EPID} / EUD(1)^{plan}| (%)	|EUD(7)^{EPID} / EUD(7)^{plan}| (%)
PTV	pass rate	-0.68	-0.92	0.25	-0.92	-0.91
PTV	γ1%	**0.95**	0.84	-0.04	0.87	0.89
PTV	mean-γ	0.85	**0.97**	-0.15	**0.98**	**0.98**
30%-PTV	pass rate	-0.79	-0.85	-0.41	-0.83	-0.80
30%-PTV	γ1%	0.68	0.85	0.76	0.83	0.75
30%-PTV	mean-γ	**0.95**	**0.98**	0.32	**0.99**	**0.98**
50%	pass rate	-0.79	-0.73	-0.50	-0.74	-0.76
50%	γ1%	**0.99**	**0.99**	0.84	**0.99**	**0.99**
50%	mean-γ	**0.96**	**0.99**	0.88	**0.99**	**0.98**

Conclusions: 3D γ parameters of the *in vivo* dose distributions are highly correlated with DVH and EUD parameters. The lack of correlation with the D99 is logical since underdosages are hardly ever observed in the PTV of *in vivo* dose distributions for H&N VMAT treatments.
These results indicate that γ criteria from *in vivo* dose evaluation that have a clinical relevance in terms of DVH and EUD parameters can readily be obtained. This pilot study paves the way for moving from hard-to-interpret γ-analysis results to the clinically more common and relevant DVH and EUD parameters. This will provide radiation oncologists with more insight in the clinical relevance of observed deviations during *in vivo* dosimetry.

OC-0159
Measurement free QA of complex radiotherapy treatment plans using a fully automated Monte Carlo verification system
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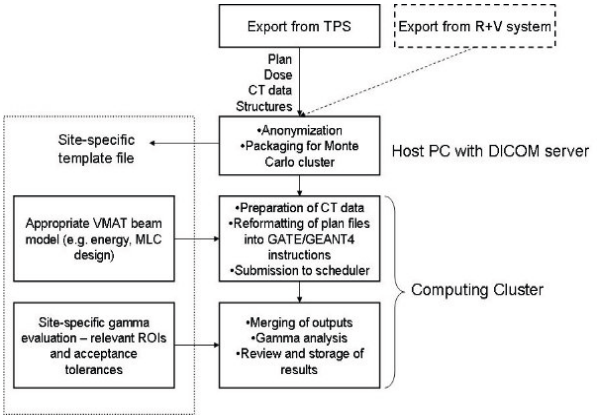
Purpose/Objective: Pre-treatment quality assurance of radiotherapy plans is an essential check of the treatment planning system (TPS) dose calculation, as well as the plan transfer to the linear accelerator. With increasing numbers of complex treatments – including volumetric modulated arc therapy (VMAT) – the burden of individual linac-based QA has implications for workflow. In this work we introduce an automated Monte Carlo verification system for VMAT treatments, with the aim of reducing or replacing linac measurements. The system allows dose statistics to be reported for individual ROIs, and is able to accept plans exported from a record-and-verify system, allowing a two-way check of plan transfer.
Materials and Methods: The verification system is triggered when DICOM-RT format files (plan, CT, structures and dose) are exported from a TPS. The system automatically prepares and reformats the files into instructions for Monte Carlo simulation using GATE/GEANT4. Calculations on the patient's CT dataset are then scheduled on a 44 CPU cluster. The outputs are automatically merged and gamma analysis performed against the planned dose distribution.
In order to validate the Monte Carlo model, comparisons were made to water tank measurements for depth-dose curves, profiles and output factors. Further validation was performed by delivering 5 prostate and 5 head and neck VMAT plans to a cylindrical phantom (Delta4), and comparing the results to Monte Carlo simulations of the same geometry. To demonstrate the potential of the system for routine use, a prostate and head and neck VMAT patient were verified and their results interpreted.



Results: The model showed good agreement against water tank measurements, with >95% of points passing a 2%/2mm gamma analysis for depth-dose curves at a range of field sizes. Validation of the VMAT simulation against the Delta4 gave results consistent with our accepted tolerance for pre-treatment QA, with pass rates of 98.6 (± 0.9) % for the prostates and 95.8 (± 2.6) % for the head and necks at the 3%/3mm gamma level.
Full dosimetric verification on a patients CT data took the system 10-12 hours on the present computing cluster, in order to achieve < 2% uncertainty within the 5 % isodose volume. By setting up verification 'templates' for individual sites, it was possible to report the gamma passes for various relevant ROIs within prostate and head and neck plans.
Conclusions: An automated Monte Carlo verification system has been developed which allows for accurate, independent dose calculations on the patient CT dataset. ROI-specific results can be reported. Export is also allowed from a record-and-verify system to check plan transfer. This system demonstrates that highly complex plan QA can be performed using a software solution, allowing for the possibility of reducing or replacing machine-based measurements. Work is now being done to determine tolerances for the calculations, and expansion of the cluster is underway to meet clinical demands.

OC-0160 Five years of experience with patient specific verifications of spot scanned IMPT.
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Purpose/Objective: In our institution, every clinical IMPT field must be verified before the delivery of the first fraction. Since 2007, when the new cyclotron was introduced into clinical practice, 2,528 IMPT fields have been verified. The purpose of this study was to analyze the results of all these fields and to decide whether patient specific verifications are necessary in the future.
Materials and Methods: The treatment planning system automatically generates a steering file per field of each plan containing the information about selected Bragg peaks, their position and weights. Dosimetric verification of every steering file then consists of a measurement of two orthogonal profiles using an ionization chamber array consisting of two arms of thirteen ionization chambers each at a single depth in water. This is mounted on an automatically controlled water column such that measurements at different depths can be performed as required. The measured profiles are directly sent to the treatment planning system where they are compared with the predicted doses.
Results: A summary of the results is shown in figure 1. The analysis of all verified IMPT fields have shown that more than 96% of verified fields were within our defined tolerances. There were no systematic errors in the position of the beam in relation to the isocenter or for the range in water. In addition, the precision (SD), calculated over all fields, is within ± 0.8 mm (SD) in all three directions. In the absolute dose, we have an accuracy of about 0.6 % of the predicted dose and precision of ±1.30 %. Although a small number of verifications were out of tolerance, most of these were due to problems with the measurement itself, e.g. chamber / water column calibration problems, malfunctioning ionisation chambers or bad cable connections.